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Review and classify the GHGs-related indicators

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ABSTRACT

Indicators can examine these changes, and monitor the use of economic and social resources, as well as the changes occurring in the efficiency of energy use and the environmental problems caused by energy use (such as greenhouse gases (GHGs) emissions). Environmental indicators can also be used to evaluate the results achieved in energy policy implementation and as a reference for the formulation of new policies. Using indicators to monitor the environmental impacts and to evaluate the efficacies of policies and regulations has been practiced for a long time; and it can serve as a useful tool for decision-making and for comparison between different countries. The objectives of this study were: (1) to conduct a literature review on the indicators that have been used in GHGs-related studies; (2) to develop a driving force-pressure-state-impact-response (DPSIR) model that incorporates GHGs-related indicators and then evaluate their relationships using a cause-effect chain of GHGs emission. This review does not aim to assess or compare different accounting systems that often support the selection of indicators, but try to organize this information that requiring clear boundaries be established, and define what will be extended implication in the future.

Contents

1. Introduction

The challenge of reducing greenhouse gases (GHGs) emission at local or global levels requires behavioral changes in life styles and energy consumption patterns in people, and the use of more

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energy-efficient production, processing and distribution technologies [1–5]. For instance, the decarbonization of fossil fuels through geological carbon dioxide (CO_2) capture and storage has the potential to significantly contribute to decreasing anthropogenic GHGs emissions [6]. Indicators have also been used extensively to deal with the policy-making issues related to GHGs in reduction, mitigation, and adaptation [7,8].

In the Fourteenth Conference of the Parties (COP-14), it reiterated that the activities to be funded should be country-driven, cost-effective, and integrated into national sustainable development and energy-efficient strategies [9]. It warrants a better understanding on the cost of GHGs reduction and the marginal damage associated with each additional tonnage of GHGs emitted into the atmosphere. As above, there is a direct relationship between GHGs emission reduction (particularly the reduction in CO_2 emissions) and individual nations' energy structure and energy utilization. Because energy supply is of vital importance to a country's economic development, climate change has become one of the most sensitive political issues for the international community.

Human activities, mainly from fossil fuel burning, have substantially increased the CO_2 concentrations in the atmosphere. They also capture the marginal contributions to climate change, which are most amenable to influence from policy and technological changes. Excessive human activities can have undesirable impacts in the long run, and these impacts including environmental degradation and climate change are captured by a negative term in the utility function. The flow of undesirable production becomes a source of inefficiency. As awareness of the potential impacts of human-induced climate change has grown, so has the desire to plan for the impacts of climate change so negative hazards can be mitigated and benefits [10,11]. Some researchers have quantified adaptive capacity based on frequency of occurrence of past hazard events [12–14]. In a vulnerability assessment framework, present-day and future estimates of adaptive capacity were sought quantitatively. Overall, the most appropriate indicators of responsibility are likely to lie between the beginning and end of the cause-effect chain [15]. The influence of adaptation and mitigation, the cost of GHGs emissions reduction, and the efficiency of energy structure of a country should be considered in the cause-effect chain.

The indicators can be physical, biological, or socio-economic and used to represent key elements of complex ecosystems and/or environmental issues. Indicators have also been used extensively to deal with policy-making issues related to GHGs in reduction, mitigation, and adaptation [7,16]. GHGs-related indicators were linked to many socio-economic and environmental indicators, including GDP growth rate, energy consumption, and environmental protection expenditures [15,17,18]. The GHGs-related indicators associate with several dimensions, including environment, ecosystem, economics, and society. For example, CO_2 emission per unit of GDP is considered as the indicator most closely related to a country's economic development [19–21].

2. The global GHGs-related indicators

2.1. International Energy Agency

IEA (International Energy Agency/Organization for Economic Co-operation and Development (OECD)) [22] built the international energy demand-and-supply databases using the national reference approach under IPCC's guidelines [23]. Generally speaking, indicator database includes: total amount emissions, CO_2 emissions per capital, CO_2 emissions per GDP, and emissions per unit energy use and statistics on 137 countries' historical CO_2 emissions from fossil fuels. The IEA's project on energy indicators was established in 1996. Their analytical framework and data developed under this project have become important tools for IEA analysis of energy use developments. The indicators (and the associated databases) help to reveal key couplings between energy use, energy prices and economic activity. This insight is crucial when assessing and monitoring past and present energy efficiency policies and for designing effective future actions. Data developed for the IEA indicator project are also used for other IEA analytic activities, such as the World Energy Outlook publication and several energy efficiency and energy technology projects within the IEA Secretariat [24].

2.2. European Environmental Agency

European Environmental Agency (EEA) management board approved the core set of indicators in March 2004 [17]. EEA's core of GHGs indicators assessment grouped by topic is: agriculture, air pollution and ozone depletion, biodiversity, climate change, energy, fisheries, terrestrial, transport, waste, and water. The assessments and projections focus on GHGs emission trends, policies and measures, and climate change impacts and adaptation actions in Europe. The EEA supports implementing the Kyoto Protocol in the EU, evaluating EU policies and developing long-term strategies to mitigate and adapt to climate change.

The EU-funded ODYSSEE [26] project's indicators are macro-indicators, defined at the level of the economy as a whole, of a sector, and as an end-use. All previous types of indicators are also expressed in terms of CO_2. Six types of indicators are considered to monitor energy efficiency trends or to compare energy efficiency performances: energy intensities; unit consumption or specific consumption; "bottom-up" energy efficiency index; adjusted indicators (to make cross-country comparisons to adjust for structural differences between countries); diffusions indicators (e.g. for monitoring); target indicators (CO_2 indicators).

2.3. The Climate Analysis Indicators Tool (CAIT)

The Climate Analysis Indicators Tool (CAIT) [15] includes a wide variety of climate-relevant data and indicators that can be viewed through an interactive and customizable interface. It provides a description and sources of the data (except for GHGs data sources), as well as a conceptual framework for classifying indicators that are relevant to climate protection. The indicators presented in CAIT are grouped into three categories: GHGs emissions, socio-economic, and natural factors. For GHG emissions-related indicators, CAIT includes numerous analysis features that allow for a range of comparisons across gases, sectors, countries, and years, its interface includes UNFCCC Parties to the Convention Secretariat, U.S. states, and countries' vulnerability and adaptive capacity. Socio-economic indicators are framed broadly and include numerous indicators related to the capabilities that countries may have to protect the climate system, including health, education, income, governance and other indicators. Finally, natural factor indicators represent those factors that tend to lie largely beyond the reach of public policy (like climatic conditions, fossil fuel reserves, and geography), but which nevertheless may significantly influence GHGs emissions.

2.4. The Organization for Economic Co-operation and Development (OECD)

An overview of recent work on sustainable development indicators in the OECD countries [25]. Much of the impetus behind these efforts is a consequence of the 1992 World Summit on the Environment and Development, where a specific agency (the United Nation's Commission on Sustainable Development, UNCSD) was

Table 1
Categories of 'Energy Efficiency' and 'Greenhouse Gas Emission' under the ESI indicators (2000–2005).

Report year	Indicator	Variables/full description	Ref. year/source
2005	Eco-efficiency	*Energy efficiency* Terajoules energy consumption per million GDP (PPP) *RENPC* Hydropower and renewable energy production as a percentage of total energy consumption	1998–2002 US Energy Information Agency (US EIA) 2002–2003 US EIA
2002	Eco-efficiency	*ENEFF* Energy efficiency (total energy consumption per unit GDP) *RENPC* Renewable resources as a percentage of total energy consumption	1999 US EIA 1999 US EIA
2001	Eco-efficiency	*ENEFF* Energy efficiency (total energy consumption per unit GDP) *RENEWP* Renewable energy (production as a percentage of total energy consumption) *WEFSUB* (subsides for energy or materials usage)	1998 US EIA 1998 US EIA 2000/The Global Competitveness Report 2000, Oxford University
2000	Eco-efficiency	*Energy efficiency (total energy consumption per unit GDP)*/energy efficiency (billion KWh/GDP) Hydroelectric plus renewable energy supply as a percentage of total energy produced Percentage increase in the supply of hydroelectric and renewable energy	1997 US EIA 1997 US EIA 1990–1997 US EIA
2005	Greenhouse gas emissions	*CO2GDP* Carbon emissions per million US dollars GDP *CO2PC* Carbon emissions per capital	2000 Carbon Dioxide Information Analysis Center (CDIAC) 1996–2000 United Nations Statistics Division, Millennium Indicator Database
2002	Reducing greenhouse gas emissions	*CO2GDP* Carbon economic efficiency (CO_2 emissions per dollar GDP) *CO2PC* Carbon lifestyle efficiency (CO_2 emissions per capita)	1998 CDIAC 1998 CDIAC
2001	Protecting international commons	*Carbon dioxide emissions* Total carbon dioxide emissions times per capita emissions *CFC consumption* Total CFC consumption times per capita consumption	1997 CDIAC 1997 CDIAC
2000	Impact on global commons	*CO2_EM* CO_2 emissions (total times per capita) *CO2HIS* Historic, cumulative CO_2 emissions	1997 CDIAC 1997 CDIAC

Source: [29,30].

established to monitor countries' efforts in developing and using sustainable development indicators. This review includes national sets of indicators covering the three pillars of sustainability (economic, social and environmental), that are presented as sustainable development indicators by the agencies developing them. All countries (Australia, Denmark, Finland, Korea, Netherlands, Portugal, Sweden, Switzerland, United Kingdom, United States, EU struct.indic) include the GHGs-related indicators for energy use and climate change, but there was an absence of science and technology indicators in Australia, Denmark, United Kingdom and United States. Indicators of energy use comprise annual energy consumption per capita, per capita consumption of fossil fuel vehicle transport (sub-indicator), share of consumption of renewable energy resources and renewable energy. GHGs indicators including: CO_2 emissions per capita, gross emissions of GHGs, gross emissions of GHGs per unit GDP, net emissions of GHGs in CO_2 equivalents, gross emissions of GHGs distributed by sector under category of climate change. Indicators of science and technology are shown in expenditure on research and development as a percent of GDP.

2.5. Environmental Sustainability Index

In constructing the Pilot 2006 EPI (Environmental Performance Index) [27], the Yale Center for Environmental Law and Policy (YCELP) built on the work of a range of data providers, including the prior data development work for the 2005 ESI (Environmental Sustainability Index) [28,29]. Target-based environmental performance benchmarks make cross-country comparisons possible on an issue-by-issue and aggregate basis. According to the characterization of the GHGs-related indicator above, Tables 1 and 2 describe a listing of these indicators and variables grouped into two categories of "Energy Efficiency" and "Greenhouse Gas Emission".

3. Classification of GHGs-related indicators

3.1. The energy of GHGs-related indicators

Energy policies are crucially linked with GHGs emissions reduction policies as well as with development policies. At the Energy Council held by the EU in 1999, approval was given for the relative list of energy indicators; including overview indicators, energy supply indicators, final energy consumption indicators, energy industry indicators, renewable energy indicators, energy efficiency, energy price and pollutant emission indicators. It was anticipated that establishing and observing these indicators would make it possible to achieve a better understanding of changes in the energy market, of the upgrading of energy efficiency, and of

Table 2
Categories of 'Greenhouse Gas Emission' under the EPI past years (2002, 2006) [19].

Report year	Policy category	Indicator	Ref. year/source
2002	Climate change	Carbon economic efficiency (CO_2 emissions per GDP)	2000 Carbon dioxide: CDIAC
		Carbon lifestyle efficiency (CO_2 per capita)	GDP: World Bank
2006	Sustainable energy	ENEFF, energy efficiency	1994–2003 Total energy consumption: USEIA GDP: World Bank
		Renewable energy	1994–2003 USEIA
		Carbon dioxide emission per unit GDP	2000 Carbon dioxide: CDIAC GDP: World Bank

Source: [19].

energy policy implementation performance, which in turn would enable governments to undertake an overall appraisal to gauge whether their energy policy is contributing to sustainable development [30–33]. Besides, the global level of CO_2 emissions indicators, several researches by academic circles and government examined particular sectors, that is, energy, industrial, household [34] and transportation [35]. Because of the positive relationship between energy and CO_2 emissions, industries with high-energy dependence were the most common review target from 1996. As well as cross-country comparisons [36], it could be presented as different sector's CO_2 emission discriminate procedures from energy demands, for example, steel, production [37].

The global community is faced with the challenge of reducing CO_2 emissions from various sources in the energy sector as this sector is the largest contributor to the anthropogenic GHGs emissions [38]. Energy related technology indicators have been discussed and advanced by several research papers in the past decade. They have examined energy intensity and energy efficiency. Some papers discuss methodologies for international comparison and evaluating indicators within various sectors [39–41].

3.2. Climate change of GHGs-related indicators

Climate change is one of the most urgent and fundamental problems facing energy market policy makers [42]. According to the COP-2 held in Switzerland Geneva (07, 1996), the 2nd report published by IPCC advances the possible direction of global warming in the 21st century and points to a discernible human influence on the global climate. The potential impacts of human-induced climate change have grown (at different levels throughout countries and sectors), and so has the desire to plan for the impacts of climate change so negative hazards can be mitigated and benefits can be enhanced.

Its clear development is a driver of human-induced climate change and that also affects development, often in a negative way [10]; both adaptation and mitigation are strongly connected to development paths. The major challenge is to make development more sustainable. Mitigation strategies reduce the emission of GHGs to soften climate change, and adaptation options for future climate change are largely drawn from the successful experience the community or system possess in coping with past and/or ongoing climatic stresses [43]. Making development more sustainable can be achieved by integrating climate change into development strategies, climate-friendly technology (i.e., getting low GHG emission economies), climate proofing (strengthening resilience against climate variability and climate change), and enhancing adaptive and mitigative capacities.

The adaptive capacity index is based on a conceptual framework of socio-economic indicators, determinants and components of adaptive capacity, for example, GDP per capita, income inequality, number of patents [14]. Factors determining adaptive capacity to climate change include economic wealth, technology and infrastructure, information, knowledge and skills, institutions, equity and social capital [14]. Using indicators of ecosystem services as measures of human well-being is similar to the approach introduced by Luers et al. [44]. So far, little research has quantified adaptive capacity, i.e., based on observations of past hazard events [12–14].

3.3. Technology of GHGs-related indicators

The global development and environmental challenges will neutralize all end-of-pipe and process-integrated measures that are developed and implemented. To counter these developments, technology must play an important role, although not all problems can be solved by it. A good example of climate strategies is R&D for controlling GHGs and for climate-friendly technologies. The role of technologies in achieving sustainable development should focus on opportunities that force technologies to develop in support of sustainability. Furthermore, energy policies are crucially linked to policies for CO_2 emissions control as well as to economic growth. The strength of the linkage varies among regions, and depends on the changing relationship of energy use to GDP over time. On the other hand, the impact of crude oil prices on energy demand is another large source of uncertainty. For oil-import countries that also have oil-producing sectors, higher oil prices would increase the flow of economic resources into oil production activities. All these exert impacts on a society that is in the process of achieving a climate-proof status. The role of technology in achieving sustainable development is focused on giving special consideration to the opportunities to force technology to develop in support of sustainability. This technical change counteracts depletion by substitution and facilitating extraction, substitution among different kinds of capital is infinite, depending only on technological change [43]. In reality, technological change is an endogenous and dynamic process influenced by the abovementioned policy and other factors affecting the acquisition of knowledge.

4. Cause-effect chain, indicators, and the PSR model

4.1. The cause-effect chain between the economy and GHGs emissions

Economic development is a driver of human-induced climate change, but climate change, in return, affects the development and often in a negative way. Both adaptation and mitigation are strongly connected to the development paths. Development can be more sustainable by integrating climate change into development strategies, making the system more climate-friendly (i.e., reduce CO_2 emission by employing improved manufacturing processes) and climate-proof (i.e., become more resilient against climate

Table 3
Recent studies concerning the scenarios of economy-GHGs-climate model.

Current results	
Assumption/goals/studies	Cost
No controls	Carbon tax: (2005 U.S. $ per ton of carbon)
Global temperature change in 2100 (°C from 1900)	
250-year delay: 3.06 °C	$1.0/ton
50-year delay: 2.72 °C	$203.6/ton
Optimal concentration limits	
2.61 °C [52]	$202.4/ton
The Kyoto Protocol with the United States participating [47].	$150 billion annually over the century (discounted to present-day (2005) value)
The Kyoto Protocol out of the United States participating [47].	$1.5 trillion
A global carbon tax that balances with the future environmental benefits from CO_2 cuts [64].	Carbon tax: current: $2/ton, the end of century: $27/ton

variations and climate change), and strengthening its adaptive and mitigative capacities.

Such emissions are largely influenced by a country's energy use and production systems, industrial structure, transport system, agricultural and forestry sectors, and the consumption patterns of its population. For full implementation of Kyoto Protocol, the cost has been estimated to be about $150 to $180 billion annually from 2008; it is significant and represents 0.5 percent of global GDP [45–47]. The scenarios analyzed on the economy and GHGs emissions and their results are summarized in Table 3. Meanwhile, current assessments conclude that the "optimal" policy should call for a relatively modest CO_2 reductions, but the suggested reductions have been modest [48]. Energy policies are often crucially linked to policies for CO_2 emissions reduction as well as for economic growth. They are linked energy demand, but the strength of that linkage varies among regions, and it depends on the changing relationship of energy use to GDP over time. The impact of world oil prices on energy demand is another large source of uncertainty. The potential effects of higher and lower oil prices on world GDP can also be found in the low and high world oil price cases [49]. For oil-import countries that also have oil-producing sectors, higher oil prices increase the flow of economic resources into oil production activities. The role of technologies in achieving sustainable development should focus on consideration of opportunities that force technologies to develop in support of sustainability. This technical change, that counteracts depletion by substitution and facilitating extraction and substitution among different kinds of capital, is infinite, depending only on technical change [43].

Numerous integrated models have been developed to estimate the cost to attain a particular path for reduction of GHGs concentrations or emissions [47,50–55]. These studies usually incorporated the costs of various impacts such as change of sea level, change of temperature, rainfall and abrupt weather, land use, ecology, environmental quality, and public sanitation. Costs were expressed as the sum of two quantities: the cost for adaptation and cost from the remaining non-adapted consequences [56]. Benefits from lower temperatures (resulted from less CO_2 emission) on agriculture, wetlands, and human life were quantified and included in the cost estimates. Nonetheless, the cost associated with emissions stabilization is still relatively large for the current generation and will continue to increase over the next 100 years [57].

Fig. 1 was developed in this study and it illustrates a cause-effect chain of GHGs emissions. The chain of causality begins with the societal actions that produce or prevent emissions of GHGs. The human activities (or the economy) is the center piece and it interacts with other pieces of the chain; they are impacts from GHGs emissions (e.g., climate change, calamity events, temperature change, abrupt weather), costs of GHGs emission reduction (e.g., costs for adaptation and mitigation), climate strategies (e.g., R&D for controlling GHGs and for climate-friendly technologies), and climate-proof society (e.g., changes in energy production, consumption, and industrial processes).

4.2. GHGs-related indicators and the PSR model

The usefulness of indicators can be enhanced by putting them into an appropriate framework or model. The Organization for Economic Co-operation and Development's (OECD's) pressure-state-response (PSR) framework is a popular environmental model [58]. A PSR framework is built on the linkages between the human activities (the pressure), the state of the environment (the state), and the societal and economic responses (the response) to an environmental change.

It provides a mechanism to monitor the status of an environment and serves as a framework for investigation and analysis. The model is a logic and holistic framework in which indicators of environmental, ecological, social, economic, and institutional characteristics can be adopted. Pressure indicators (e.g., CO_2 emission) describe social and economic activities or variables that exert impacts on the environment. State indicators (e.g., global mean temperature) show the state or conditions of the environment and indicate the degree of improvement or degradation of the environmental condition. Response indicators (e.g., emission reduction regulations, tax incentives) demonstrate the efforts of a society and its policy makers in response to the condition of the environment in the process of achieving sustainable development. Good assessments based upon these three sets of interrelated indicators can help in decision-making; however, trends of indicators should be used only to illustrate the possible pathways rather than predict the future [59].

Selecting which indicators to be focused on in a PSR framework depends on what issues or progress are to be examined. There would be no universal set of indicators and selection may vary by region or by country. Data availability is also an important criterion. As part of this study a literature review was conducted on

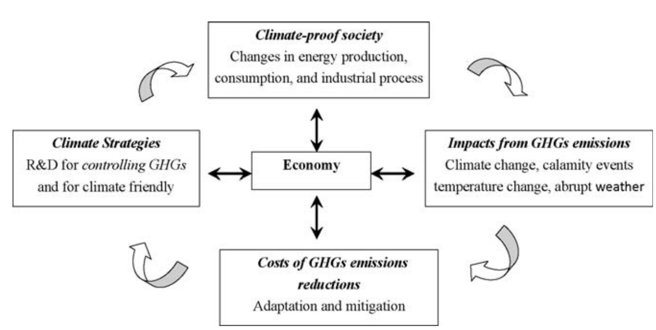

Fig. 1. A schematic overview of the cause-effect chain for the GHGs emissions.

Table 4
GHGs-related indicators used in pressure-state-response frameworks.

Category	Group	Indicators	Sources
Environmental pressure			
Single	1. Air pollution	CO_2 emission	[9,61,64,65]
	2. Air quality	CO_2 concentration	[9,61,64,65]
	3. Water quality	BOD, POP	[25]
	4. Waste	Waste recycle rate	[25]
	5. Total GHGs emissions	CO_2 intensity of consumers	[9,61,64,65]
Aggregate/composite	1. CO_2 savings in sectors	CO_2 savings in industry	[24]
	2. Material use	Ecological footprint per unit of GDP	[25]
Economic-social pressure			
Single	1. Energy use	Tons of oil equivalent	[9]
	2. Climate conditions	Heating (cooling) need	[9]
	3. Ratio of renewable energy use	Hydropower and renewable energy production as a percentage of total energy consumption	[47,6]
	4. Energy efficiency	Energy efficiency by country GDP per capita	[9,61,64,65]
	5. Adaptive capacity		[14–16]
Aggregate	1. Decoupling indicators		[25]
	2. Adjusted indicators	Energy intensity adjusted for prices, climate, industry and economic structures	[24]
Ecological state			
Single	1. Global average temperature		[25]
	2. Extreme weather events	Flooding, precipitation	[25,64,65]
		Annual river discharge	[25]
	3. Ecosystem		[25]
	4. Biodiversity	Total land impacted by human activity	[9]
	5. Geography		
Aggregate/composite	1. Vulnerability		[16,64,65]
	2. Sensitivity		[16]
Institute-political response			
Single	1. Economic growth	GDP, income	[9,25]
	2. Environmental expenditure and tax		[9,25]
Aggregate/composite	1. Governance	Index value of six area of governance	[9,25]
	2. Target indicators (Indicators of technical progress)	Space heating	[24]
		Large electrical appliances	[24]

Note 1: The term decoupling refers to breaking the link between "environmental bads" and "economic goods". Decoupling can be measured by decoupling indicators that have an environmental pressure variable for numerator and an economic variable as denominator (OECD Environmental Minister, 2001).

the indicators that have been used in the areas related to sustainable development, environmental quality, energy use, and GHGs emissions. The results are summarized in Table 4. These indicators were classified into three groups under the PSR scheme: pressure (environmental or economic-social), state (ecological), and response (institute-political). The indicators were further classified into two types: single or composite (a composite or aggregate indicator means an aggregation of indicators with similar impacts). Overlapping between the indicators is common and relatively obvious because the complexity and interdependency of the components in the cause-effect chain of GHGs emission.

4.3. A DPSIR framework for GHGs emissions

Differ from the categorization of indicators as Section 4.3 has shown. The driving force-pressure-state-impact-response (DPSIR) framework seems highly capable of showing information in an analytical, causal way when differentiating between causes and effects as well as human measures and responses to control the amount of impacts to end users [60]. The DPSIR model can also be used as the basis for the analysis of ecosystem-society interactions and allow users to identify the main drivers of change for each site.

As above, we try developing a modified DPSIR framework to combine GHGs-related indicators and explain their relationships using the cause-effect chain of GHGs missions. The framework was modified from the IPCC's approaches [61] and it is illustrated in Fig. 2. It starts from the category of human activities that includes indicators for energy production, consumption, and other industrial process; and these indicators are considered as indirect-drivers. Source for data of direct-drivers can be from the statistical or socio-economic departments of a government, while the impacts can be assessed the data collected by the authority in charge of local monitoring. The subsequent category is GHGs emission, and its indicators are considered direct-drivers. It is then followed by categories of GHGs concentration (pressure indicators), change in temperature (state indicators), environment impact (impact indicators), and climate strategies (response indicators). This PSR model is mainly related to energy consumption, environmental impacts, and policy responses. It uses a broader definition of capital, which includes natural capital and

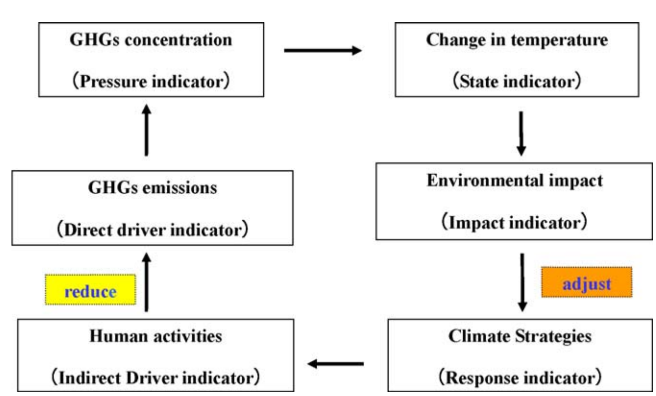

Fig. 2. A multi-dimension GHGs-related indicator framework.

Table 5
GHGs-related indicators considered for the modified DPSIR framework.

Category/dimension	Type	Indicators		Relationship with sustainability
Human activities	PA	Per capita energy consumption	–	The goal of sustainable development is to achieve a zero increase.
	PA	Value of average energy imported per capita/per capita national income (value of imported petroleum/GDP))	–	A decrease in this ratio implies energy use efficiency.
	PA	Energy price per GDP (total cost of energy demand)	–	The ratio can serve as a check of the economic development.
	PA	Effective technology for CO_2 recycle and storage (target: 2050)	+	An increase in this ratio implies GHGs emission control efficiency.
	PA	Carbon intensity of electricity production	–	A decrease in this ratio implies energy use efficiency.
	PA	Climatic condition	–	A decrease in this ratio implies energy use efficiency.
GHGs emission	E	Total amount of CO_2 emissions (million metric tons CO_2)	–	The goal of sustainable development is to achieve a zero increase.
	E	Emission of per unit energy	–	A decrease in this ratio implies energy use efficiency.
GHGs concentration	E	CO_2 per capita	–	The goal of sustainable development is to achieve a zero increase.
Change in temperature	PI	Change in average temperature		The goal of sustainable development is to achieve a zero increase.
Environmental impact	RI	Total land area affected by human activity (including: forest, arable land, transport land)	–	Reduction of land areas is considered harmful to sustainable development, this index also influences areas of field and animals' habitat.
	RI	Ratio of biological diversity (%)	+	An increase in this ratio indicates better preservation of resources and the ecosystem, which is beneficial to sustainable development.
	RI	Forest density (%)	+	Reduction of forest areas is considered harmful to sustainable development.
	RI	NDVI (normalized difference vegetation index)		
	RI	Frequency of calamity events	–	An increase in frequency and magnitude of nature hazard events indicates a vulnerable position.
Climate strategies	AC	CO_2 emission per unit of GDP		The indicator reflects energy structure in a country.
	AC	Energy use (ratio of total energy requirement (consumption) growth, carbon intensity of energy use, energy efficiency)	–	A decrease in this ratio implies energy use efficiency.
	AC	Ratio of renewable energy use	+	An increase in this ratio implies energy use efficiency.
	AC	Ratio of environmental budget to total government budget (the percent of GDP on R&D)	+	A higher budget allocation for the environment and conservation of natural resources will assist in the drive towards sustainability.
	AC	Government tax incentives for pollution prevention (carbon tax, green tax, energy tax)	+	An increase in government incentive measures will help to achieve the sustainability of the industry and of the environment.

Note: E, exposure; PI, potential impacts; AC, adaptive capacity; PA, planned adaptation; RI, residual impact.

human-induced capital (knowledge or R&D); it also allows some degree of substitution among different types of capital.

4.4. Selection of indicators

Table 5 lists the relevant indicators that can be used in our DPSIR framework. They are classified into six categories/dimensions (human activities, GHGs emissions, GHGs concentration, change in temperature, environmental impact, and climate strategies) as defined in Fig. 2 earlier. Each single indictor in a category can also be composited to an aggregate (group) index to reflect different influence and degree. Vulnerability of a given system is related both to its exposure (E) to GHGs effects and to its adaptive capacity (AC) to deal with those effects. The definition of the term is "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate, including climate variability and extremes". It include the potential impacts (PI) of GHGs emission on change in average temperature, the planned adaptation (PA) defined it as the capacity to which human and environmental systems are likely to experience harm due to perturbation or stress, and residual impact (RI) means an impact assessment (i.e., sensitivities of a system to exposures).

Six indicators in the category of human activities are shown in Table 5. They are the indirect driver in cause-effect chain of GHGs emissions. Because the GHGs concentrations increased from human activities but mitigated by the climate strategies include R&D for controlling GHGs and for climate-friendly. 'Average energy consumption per capita can be used to reflect the energy use on per capita basis. 'Value of average energy imported per capita/per capita national income', calculated as total energy consumption divided by real GDP, refers to the amount of energy needed to produce each real unit of GDP. A decrease in this ratio implies that less energy is needed to create each unit of real GDP; and the energy efficiency increases that will have a positive influence on environment. On the other hand, a decrease in the indicator of 'energy price per unit of GDP' reflects a decrease of energy price or increase of GDP. It also can serve as a check of the economic development. 'Effective technology for CO_2 recycle and storage' reflects the role of technologies in achieving GHGs emissions control. For example, decarbonizing fossil fuels through geological CO_2 capture and storage has the potential of significantly reducing anthropogenic CO_2 emission. In the short term, CO_2 capture and storage might play an important role in mitigating climate change [6]. 'Carbon intensity of electricity production' measures carbon emissions per unit of electricity (kilowatt-hour, or kWh) generated. Two indicators are used to express climatic condition, heating and cooling degree days (HDD and CDD). The 'degree-day' is a measure commonly used to evaluate demand for heating and cooling service.

In our DPSIR framework, the direct-driver indicators of the GHGs emission category include 'total amount of CO_2 emissions' and 'emission of per unit energy'. The indicator of 'CO_2 per capita' in the GHGs concentration category measures CO_2 emissions on a

per-capita basis. The indicator of "change in average temperature" in the category of change in temperature means the changes to the climate resulted from temperature increase. It has gained considerable attention because this kind of indicator was proposed by the delegation of Brazil during the 1997 Kyoto Protocol negotiations. The indicators in the category of environmental impact include total land area affected by human activity, biological diversity, forest density, NDVI (Normalized Difference Vegetation Index), and the frequency of natural hazards. For example, NDVI is related to an ecosystem that could reflect the plant growth. A larger NDVI value means higher productivity in an area [62]. An increase in frequency and magnitude of nature hazard events indicates a vulnerable position. Formal policies and procedures may need to be designed and implemented to mitigate and remediate the problem.

The response indicators in the category of climate strategies include energy efficiency, renewable energy use, environmental budget, expenditure on R&D for CO_2 reduction or energy efficiency, and the CO_2 emission per unit of GDP. The indicator of CO_2 emission per unit of GDP is most closely related to a country's economic development [19–21]. As a significant driver of GHGs emissions, countries with high intensity of energy use per person may be more capable of limiting or reducing GHGs emissions than those countries with low intensity of energy use [63]. Carbon intensity of energy use measures the carbon content of a country's energy consumption. CO_2 emission per unit of GDP means emissions intensity from fuel mix or, more specifically, the carbon content of the energy consumed in a country. The 'ratio of environmental budget to total government budget' does not include day-to-day environmental sanitation and maintenance spending, factory (facility) safety equipment spending, 'good-neighbor' expenses, spending on emission compensation or fines, and funeral service expenditure. 'Government tax incentives for pollution prevention' comprises all the government spending in terms of grants and incentives for the purpose of improving the structure of industry and thereby alleviating the pressure on the environment. It reflects the degree of commitment to emission control and the results obtained, and are currently calculated from the total annual amount of funds granted to firms that have applied for subsidies to offset their investment in emission prevention or technology. This indicator can also show how the industrial structure is changing.

5. Conclusions

In dealing with the complex issues of greenhouse gases (GHGs) emission and climate change mitigation, many interrelated factors such as cost, level of technology development, supply and demand of energy, structure of industry, and expenditures on R&D exist. Using indicators to monitor the environmental impacts and to evaluate the efficacies of policies and regulations has been practiced for a long time; and it can serve as a useful tool for decision-making and for comparison between different countries. Although numerous indicators have been developed for relevant subjects, integrated approaches that consider the individual changes, dynamic interaction, and hidden-impacts of indicators are scarce.

Establishing and redefining the indicators helps understand the changes taking place in the environment. Such an explanation may partly explain the simplicity of the relation of the GHGs relative indicator system, but its not entirely convincing. The more likely explanation tests the nature of communicative setting. One should consider the delay and accumulation of the GHGs effect, and elasticity of impacts from GHGs emissions set for future research. Therefore, the findings and implications of the study should be generalized to the extent future assessment of scenarios is similar to the participants. The findings suggest different orientations are not necessarily mutually exclusive.

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